AVALANCHE PHENOMENA IN TWO-DIMENSIONAL FOAM SYSTEMS

Tohru Okuzono† and Kyozi Kawasaki‡
†Department of Physics, Ochanomizu University, Tokyo 112, Japan
‡Department of Natural Science and Mathematics, Chubu University, Kasugai-shi 487, Japan

A foam system is constructed with a network of liquid films as a consequence of dense random packing of gas bubbles. When the foam system undergoes a shear deformation, topology changes of the network, or rearrangements of bubbles, can take place. In the previous numerical studies[1], we showed that such rearrangement events called avalanches intermittently occur in large strain regimes followed by disordered flow. Both the size distribution of avalanches and the power spectra of response functions exhibit power-law behaviors.

Experimentally, the rearrangement dynamics in foams can be probed by diffusing-wave spectroscopy (DWS)[2]. Recently, DWS technique has been applied to flowing foams[3, 4]. Gopal and Durian[4] in their DWS measurement obtained the result that the dynamics of shear-induced rearrangements has a single characteristic time, which seems to contradict our simulation results. In this paper we present newly analyzed simulation data which may correspond to the observable quantity in a DWS measurement.

In our two-dimensional model[5] a foam system is expressed as a network which consists of vertices connected by straight bonds(edges). Equations of motion of the vertices are derived from force balance equations at each vertex between film tensions and friction forces including the viscous force arising from the liquid motion in the films.

In DWS measurements, the temporal autocorrelation function of the electric field of the multiply-scattered light is obtained[6]. The autocorrelation function $g_1(t)$ with the delay time t is related to the dynamic structure factor in DWS theory[7]. According to this theory we may calculate the following quantity which should be proportional to $g_1(t)$:

$$g_1(t) \propto \sum_n P(n) \left[\frac{\langle\langle \rho_{\mathbf{q}}(t)\rho_{-\mathbf{q}}(0)\rangle\rangle_{\mathbf{q}}}{\langle\langle \rho_{\mathbf{q}}(0)\rho_{-\mathbf{q}}(0)\rangle\rangle_{\mathbf{q}}} \right]^n , \tag{1}$$

where $\rho_{\mathbf{q}}(t)$ is the Fourier component of the film density with wave-vector $\mathbf{q}$; $\langle \ \cdot \ \rangle$ and $\langle \ \cdot \ \rangle_{\mathbf{q}}$ denote the ensemble average and the average over all possible wave-vector transfers $\mathbf{q}$, respectively. $P(n)$ is the weight function of light path of order n contributing to the total scattered intensity. This weight function depends on the appropriate experimental geometry, but here we use the following expression: $P(n) \propto \frac{1}{4\pi Dn}\exp(-L^2/4Dn)$, where L is the system dimension and $D \equiv l^{*2}/2$ with the transport mean free path l^*.

The simulation was carried out for the same situation as in Ref.[1]. We show in Fig. 1 the semi-logarithmic plot of $g_1(t)$ vs. $t^{1/2}$ for three different time regimes: (a) small strain regime in which no avalanche occurs, (b) large strain regime in which avalanches occur frequently, and (c) relaxation regime with no increase of shear deformation after large deformation, corresponding to circles, squares, and triangles, respectively. Here we have used the experimental value 3.5 for l^*[4]. The average over $\mathbf{q}$ in Eq.(1) has been replaced by the circular average for $|\mathbf{q}| = 2\pi \times 10$ fixed, since $g_1(t)$ is not largely affected by $\mathbf{q}$. From this figure we see that in each case $g_1(t)$ behaves like

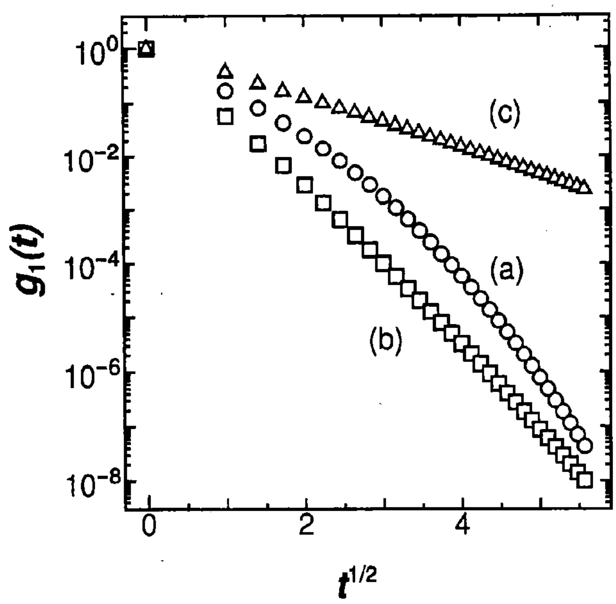

Figure 1: Semi-logarithmic plot of $g_1(t)$ vs. $t^{1/2}$ for the three different time regimes: (a) small strain regime (circles), (b) large strain regime (squares), and (c) relaxation regime (triangles).

$\exp(-\Gamma\sqrt{t})$ for small t (Γ is a constant) as described in the DWS theory for uncorrelated dynamics and that avalanches or shear-induced rearrangements cause a larger initial decay rate compared with those in the cases (a) and (c). This result will not contradict with the experimental result[4], although our model does not describe the coarsening dynamics.

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